THE PHASING-OUT OF ALTERNATING-CURRENT APPARATUS.

By J. HACKING, STUDENT.

(*Paper read before the* NEWCASTLE STUDENTS' SECTION, *6th January*, 1913.)

In the following paper I propose to touch briefly on the principles underlying the tests which are made to ensure that the various phases of newly-installed alternating-current apparatus bear the correct relationship to one another and to the corresponding phases of other apparatus with which it might be required to run in parallel, and also to give some account of the way in which these principles are applied to the actual phasing-out of several classes of apparatus. The paper is intended to deal only with alternating-current apparatus, but the simple fundamental case of two continuous-current generators is first considered for simplicity of illustration.

CONTINUOUS-CURRENT GENERATORS.

Suppose we have two generators which are intended to run in parallel. For this connection it will be necessary to see that the positive terminals of the two machines are connected to the same busbar; and similarly with the negative terminals. Before the connections are finally made, however, it is necessary to find which of the two terminals of each machine is positive, and which negative. This may be done by means of pole-finding paper, but as this test is not permissible with alternating-current machinery it will not be dwelt on here. The test which immediately suggests itself is to compare the voltage of one machine with that of the other. This may be done by connecting the two machines together at one point, and taking voltage readings across the remaining terminals. If two terminals of like polarity are connected together, the pressure read between the other two terminals will be zero if the voltages of the two machines are equal, whilst if a negative and a positive terminal were connected together, the pressure read would be equal to twice the pressure of either generator.

Another method would be to get two voltmeters of equal resistance, or two banks of lamps, and connect up the two machines through these. If the voltmeters were each connected between terminals of like polarity, they would each read zero, whilst in the other event the machines would be put in series through the voltmeters, and, the resistance of the voltmeters being equal, each voltmeter would read the voltage of either generator. It is evident that "static" voltmeters are not so convenient for this test as those which have a definite circuit through them. If "static" voltmeters were used, the algebraic sum of the two readings would be zero for correct connection, and twice the voltage of each machine for reversed connection.

It would of course be of no use to connect a single voltmeter between one terminal of each machine and leave the other terminals open, as the result would be simply to bring the two points so connected to the same potential, the function of a generator being, not to maintain any definite potential at its terminals, but to maintain a potential difference between the terminals.

If, in the second test mentioned, one of the voltmeters used had a resistance twice that of the other, the voltage read by it would be twice that read by the lower resistance instrument, since the reading given by either instrument is proportional to the voltage drop across it. It will be seen that because of this the second method is not so likely to give accurate results as the first, although, of course, the readings in this case would be accurate enough for the purpose.

Transformers.

Transformers fed from a common source are often required to run in parallel on the secondary side, and it is to such transformers that the following remarks on transformer phasing are applied. Such transformers differ from rotating machinery in that their voltage vectors always maintain the same relative positions, and it is therefore possible to carry out phasing tests with one voltmeter or bank of lamps. In the case of rotating machinery, however, since the vectors of one machine swing relatively to the vectors of another until they are actually running in parallel, it is necessary to connect across all phases, either directly or through voltmeters or lamps.

Single-phase Transformers.—Two single-phase transformers can be phased out in exactly the same way as the two continuous-current generators treated above. If the secondary of each transformer is wound similarly with respect to its primary, the transformers should be connected up symmetrically, but if one were wound relatively opposite to the other, the effect of symmetrical connection would be to put the two transformers in series through the busbars. Evidently then this must be taken into consideration when connecting up. It can be determined either when making the tests outlined above or by the following test:—

Connect one primary terminal to one of the secondary terminals. If a low pressure is then applied across the higher voltage winding, a voltmeter connected between the two open terminals of the transformer will read either the sum or the difference of the primary and secondary voltages, depending on the relative direction of winding. In the former case the transformer is said to be of positive polarity, and in the latter case of negative polarity. It is of interest to note here that if the second test—that is, with two banks of lamps or voltmeters of equal resistance—is adopted, the potential drop across each bank of lamps is half the resultant voltage of the circuit, even if it should so happen that the transformer voltages differ vectorially.

Three-phase Transformers.—Since it is necessary in phasing-out to ascertain that the various phases bear the correct relationship with one another before determining whether they bear the correct relationship with the apparatus with which they are required to run in parallel, it is necessary in the case of three-phase transformers to ensure first of all that the phase vectors of the three phases are 120° apart. In star transformers, for instance, it is quite conceivable that one phase may have been reversed with respect to the other two, and readings taken between the three phase leads would give readings equal to the line volts, 0·58 times the line volts, and 0·58 times the line volts respectively. In meshed secondaries it is necessary to ensure that this error has not been made before the mesh is completed, as the result would be to cause a heavy circulating current to flow in the windings. This may be done by leaving the last meshing connection off, switching in the transformer primary, and connecting a voltmeter across the two open-circuited terminals. If correct, the voltmeter will indicate zero, whilst if a phase does happen to be reversed, the reading will equal twice the line pressure.

To apply the second of the two tests mentioned at the beginning of this paper to three-phase transformers would necessitate the use of three voltmeters or three banks of lamps, unless, indeed, two sets were used and the phases were connected up two at a time. As, however, by first connecting one point of one transformer secondary to one point of the other, only one voltmeter is required; this is the test usually adopted, the points connected being where possible the neutral points of star windings, and where this is not possible, two phase terminals. As in the case of single-phase transformers, symmetrical connections will give the desired result if the transformers are on all phases of the same polarity, whereas if of opposite polarity on all three phases they will be 180° out of phase, and the voltages read between corresponding secondary terminals (neutrals linked) will be equal to twice the phase voltage. It is interesting, however, to trace the effect of various errors of connection on the readings obtained, and the vector diagrams of Figs. 2 and 3 have been drawn up to show the result. In order to get reliable readings for this purpose in the case of mesh windings, or of star windings where the star points are inaccessible, it is necessary to connect each pair of phases in turn, as the results vary accordingly.

The significance of the letters in the vector diagrams of Figs. 2 and 3 is shown in Fig. 1, where it is assumed that the secondaries of one transformer are connected to the three terminals *a*, *b*, and *c*, of a switch, and the secondaries of the other transformer are connected to the other three terminals A, B, and C, of the switch. The voltage obtained between any two terminals of this switch is proportional to the distance between the corresponding points on the vector diagram. The vectors of one transformer are shown in full lines, and of the other in dotted lines. The six diagrams given in each figure show all the results possible, as any combination of the single errors reverts to one of these diagrams.

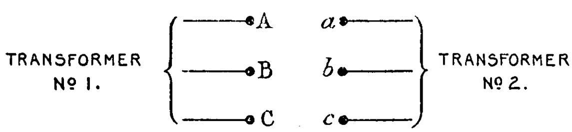

Fig. 1.

Fig. 2 gives the cases in which the neutrals of the secondary windings are connected together to form the common point, and is, therefore, only applicable to mesh-star or star-star transformers, except when three voltmeters or lamps are used, when it applies to any windings. Fig. 3 refers to either mesh-star or star-star transformers where the neutrals are inaccessible, and also to star-mesh or mesh-mesh

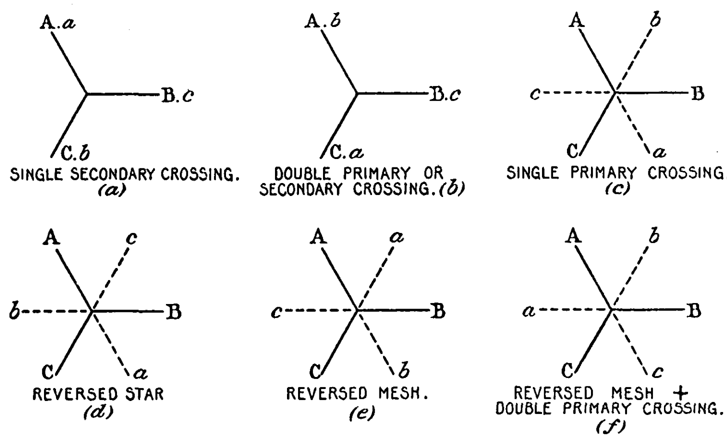

Fig. 2.

transformers. In transformers similarly connected on both primary and secondary—that is, in star-star or mesh-mesh transformers—the effect of a primary crossing will evidently be the same as that of a secondary crossing, and the diagrams referring to primary crossings must therefore be deleted.

If with three-phase transformers the three-lamps or three-voltmeters method of phasing-out be adopted for any reason, the results obtained for various errors of connection will be exactly the same for all classes of transformers, as is shown in the various diagrams of Fig. 2. The comparison of polarity of three-phase transformers can be carried out in exactly the same way as with single-phase transformers, a single-phase supply being utilized for the test.

It has been said that if two transformers of the same polarity are connected up symmetrically they will phase out correctly. The symmetrical connections are not intended to refer only to the application of the three-phase supply, but also to the actual mesh or star connections. It is evident that there are two methods of connecting in mesh or in star the phases of any winding. With star windings either the bottom or the top ends of the coils can be connected together to form the star point, and in mesh windings the mesh may be made

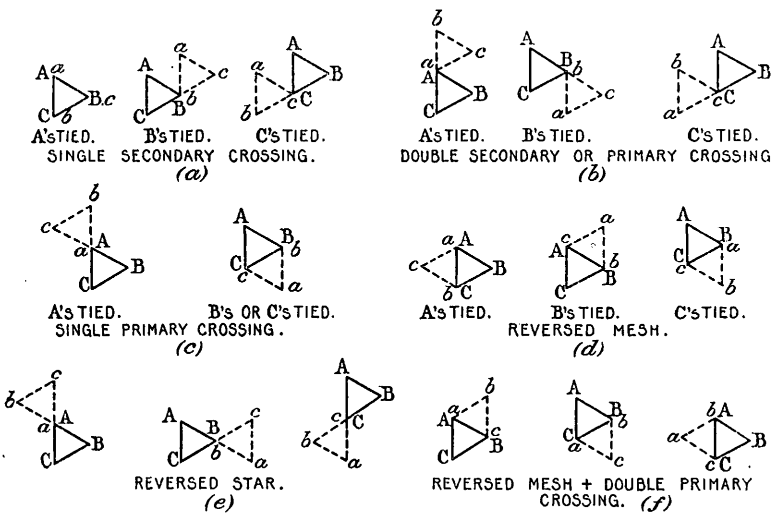

FIG. 3.

either by connecting the top of limb 1 to the bottom of limb 2, etc., or by connecting the bottom of limb 1 to the top of limb 2, etc.

In the reversed mesh and reversed star diagrams of Figs. 2 and 3, one transformer is taken to be connected in mesh or star in one of these alternative ways, whilst the other transformer is connected in mesh or star by the other alternative method.

The effect of reversing the star is evidently just the same as reversing the polarity. The effect of what may be called reversal of mesh does not, however, produce this result unless the primary connections are suitably crossed. The reason for this is shown in Fig. 4 (*a*) and (*b*). Fig. 4 (*a*) shows one way of connecting the winding in mesh and the natural way of bringing out the connections, whilst Fig. 4 (*b*) shows the other way of connecting the winding in mesh and the natural way of bringing out the connections. The result is that the top connections of the coils are still brought out in the same order as before. Now, if these two transformers were connected up symmetrically, the E.M.F. vector applied across each limb of the second transformer would not be 180° displaced from the E.M.F. vector applied across the corresponding limbs of the first transformer. The vector diagram would be as shown in Fig. 2 (*e*) and Fig. 3 (*d*). In order to get this 180° phase displacement between corresponding limbs, it would be necessary to connect the second transformer as shown by the top line of letters in Fig. 4 (*b*), so that whereas in the first transformer No. 1 limb was connected between R and B phases, in the second transformer it would be connected between B and R phases, etc. This is the reason for (*e*) in Fig. 2 not corresponding with (*d*).

Reverting to the diagrams of Fig. 2, it is seen that providing the vectors of one transformer coincide with the vectors of the other transformer, as in diagrams (*a*) and (*b*), it is possible to make the transformers phase out correctly with suitable secondary crossings. Further, in mesh-star and star-mesh transformers if the vectors of the two do not

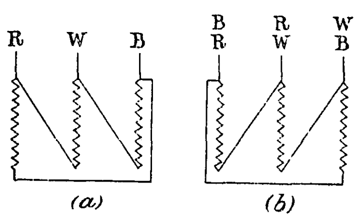

FIG. 4.

coincide (see Fig. 2 (*c*), (*d*), (*e*), (*f*),) it is possible to make them coincide by merely crossing two of the primary leads. It will therefore be seen that no matter what the internal connections or what the polarity of two mesh-star or star-mesh transformers, they can be correctly phased out by making suitable primary and secondary crossings. With transformers of like connection on the primary and secondary, however, since a crossing in the primary has only the same effect as a crossing in the secondary, the internal connections and polarity of the transformers will determine the possibility of phasing-out. If, however, the windings on one side of one of the transformers are connected in mesh or star outside, a suitable alteration of the mesh or star connections, taken in conjunction with suitable crossings, will enable the transformers to be correctly phased.

In some cases two transformers have to be able to run a number of motors in the same direction, but are not required to run in parallel. It might in such a case be desirable to find if the sequence of phases is correct for the purpose. This may be done if the vector diagrams of the two transformers are drawn from results obtained in the phasing tests. If, for example, in any of the diagrams of Figs. 2 and 3 the terminals A, B, C, on being traced round follow the same direction, clockwise or counter-clockwise, as the terminals a, b, c, the direction of vector rotation is the same for both transformers, and each transformer will therefore run motors in the same direction.

Transformers of similar connection only have so far been considered as being required to run in parallel. It is useful, however, to investigate the possibilities of running two transformers of different connection in parallel. It is not necessary, however, to go fully into this here, as a study of the diagrams for various connections will show that while star-star transformers will run in parallel with mesh-mesh, and mesh-star transformers will run in parallel with star-mesh transformers, it is altogether out of the question to attempt to parallel mesh-star transformers with star-star or mesh-mesh.

Such connections as open mesh and three-phase Tee have not been considered at all here, as they are not so commonly met with. The same principles can, however, be applied to them by anyone sufficiently interested in the subject.

Alternating-current Generators.

The treatment of this class of machinery is rather different from that required by transformers and continuous-current generators, as in addition to the conditions to be fulfilled in their cases it is also necessary to determine the instant at which they can be paralleled—that is, to synchronize. For this reason it is inevitable that the question of synchronizing should be to a certain extent involved in that of phasing-out. As this paper is not intended, however, to deal with synchronizing connections, reference to them will be confined to the checking of the accuracy of the synchronizing arrangements by comparison with the phasing tests. A phasing test of necessity shows the point of synchronism in addition to the other factors, and if the permanent synchronizing connections are made and tried at the same time as the phasing test, their accuracy can be checked. The connections for the actual phasing-out test are usually only of a temporary nature, and apply to all phases, and once generators are correctly phased out it is only necessary to synchronize them on one phase.

It is not necessary to phase out single-phase generators, but only to synchronize, as even if one generator did happen to be reversed with respect to another, the two would again be in phase after they had moved relatively one half-period. Either of the two methods outlined earlier in the paper may be used. If the generators are of high pressure it is desirable to use potential transformers, and the primaries of these may be connected exactly as were the lamps and voltmeters previously used, the lamps in this case coming into the secondary side of the potential transformers. Another way of using potential transformers—the usual method of synchronizing high-tension alternators—is to connect the primary of each transformer to the terminals of each alternator, the secondaries being connected through lamps. It is evident that by so arranging the secondaries the lamps can be connected so as to be either bright or dark at the point of synchronism, and, although the usual synchronizing practice is to have bright lamps at synchronism, in what follows with reference to this method it is assumed that the connections are so made as to have the lamps dark at synchronism. This renders the results obtained the same with potential transformers in use as without. In all cases where two or more potential transformers are used in this way, it is first of all necessary to test the transformers back to back by one of the methods mentioned under "single-phase transformers."

Three-phase alternators should first of all be tested for reversed phases in the same way as transformers, and it is assumed that this has been done. The usual method of phasing-out is to connect potential transformers or lamps directly between the corresponding terminals of the two machines, and it is immaterial whether the neutrals—if the windings are star-connected—are connected together or not. It is possible, however, to do away with one transformer or one set of lamps by bridging across two corresponding terminals instead of connecting them through a lamp. In this case, as will be shown later, the transformers or lamps will have to be able to stand a higher pressure than in the other case. Care must also be exercised to ensure that the neutrals of the windings are not already connected. The method of connecting one set of potential transformers to one machine and another set to the other machine, and inter-linking the secondaries through lamps, can also be used. In this way four potential transformers will be required—that is, two sets of two transformers connected in open delta.

It is now necessary to run both alternators at approximately synchronous speed. As the speed of the two will differ slightly, the vectors of one will rotate slowly with respect to the other. We can then consider the vectors of one alternator as fixed and the vectors of the other as rotating slowly. By comparing the voltage obtained between any two corresponding terminals for several relative positions of the two sets of vectors, it will be seen that, if correct, the three lamps will brighten and darken together. The only possibility of error is that the vectors of one alternator will follow in one direction, say 1–2–3, and the vectors of the other in the other direction, 1–3–2. If this is the case, each of the three lamps will brighten and darken in turn. A crossing of any two phases of either machine will give correct results.

To determine the maximum voltage which any potential transformer has to stand, that vector position which gives a maximum value of the voltage between any two corresponding terminals may be drawn. Thus, whereas in the first method mentioned above the transformers must be capable of dealing for short periods with a pressure equal to 1·155 times the line pressure, in the second method they must be capable of dealing with twice the line pressure. In the third method the potential transformers themselves will of course only be required to stand the ordinary line pressure, but the lamps used will have a maximum voltage impressed on them equal to 1·155 times the low-tension pressure of each transformer.

The correct instant of synchronism is when the lamps are dark, and the permanent synchronizing connections may be checked against this.

There is another method of phasing out an alternator, which is of practical interest as it makes use of the permanent synchronizing arrangements together with only one additional potential transformer. If the neutral point of the incoming generator is connected to the neutral point of the system on which it is required to run, the additional transformer will be required to stand a pressure of 1·155 times the ordinary line pressure for short periods, whilst if the neutrals are not connected it must be able to stand twice the line pressure.

It is assumed in the following description of this method that, as is usual, the machine synchronizing element is single-phase, and that the neutral points are not connected. The accuracy of the indication of the synchronizing position by the synchroscope or other means provided is first tested in the following way: Disconnect the cable connecting the machine and the switch at the machine terminals, or at any other convenient point between the potential transformer of the machine and the machine itself. Now close the switch and try the synchronizing gear. This should indicate the synchronizing position. As an additional test, the effect of reversing the leads of the alternator potential element may be tried. This should cause the synchronizing gear to indicate the "180° out of phase" position.

The potential transformer connections should now be made normal and the alternator itself re-connected. The additional potential transformer is connected between corresponding terminals of the switch, in that phase to which the synchronizing potential transformer is not connected, and the corresponding terminals of the switch in another phase are bridged across. Connect a voltmeter in the secondary of the additional potential transformer. Now run the alternator up to synchronous speed. The synchronizing gear will indicate when the phases to which the machine potential transformer is connected are in phase with the corresponding busbar elements, and if the cyclic order of phases on the alternator is correct; the voltmeter in the secondary of the additional transformer will at the same time be reading zero. If, however, the cyclic order is reversed, the voltmeter will give a reading corresponding to 1·73 times the line pressure—that is, slightly less than the maximum pressure it receives—when the synchronizing gear shows the point of synchronism.

If the neutrals are connected, the connection bridging the terminals of one phase of the switch must be left off, the rest of the procedure being as before. In this case, if the cyclic order of the phases is reversed, the voltmeter will give its maximum reading when the synchronizing gear indicates synchronism.

ROTARY CONVERTERS.

Not Self-starting.—The usual connections of rotary converters operating on three-phase systems are: three-phase, six-phase double-delta, and six-phase diametrical-star. The first can be treated in exactly the same way as three-phase generators. As, however, synchronizing is usually carried out on the high-tension side, whilst phasing-out is effected on the low-tension side, the permanent synchronism indicator will not rotate as when normally running up, but will definitely indicate the synchronizing position. This will also be the case with the other two classes of connections. The six-phase double-delta connection and the six-phase diametrical connection have greater possibilities of error than the ordinary three-phase connections, but if certain preliminary tests are made they can be reduced to the same footing.

Fig. 5 shows the transformers and slip-rings for a six-phase double-delta rotary converter, the small numbered circle showing the position of the armature tappings connected to the various slip-rings. If any difficulty is experienced in tracing out these tappings, the order of the slip-rings can soon be located by running up the machine to about

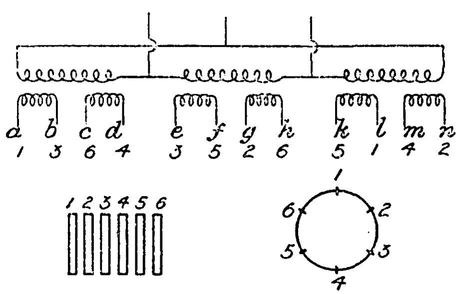

FIG. 5.

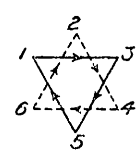

FIG. 6.

synchronous speed, and taking voltage readings between the various rings. The rings can then be numbered accordingly. The secondary of each transformer is split into two sections, one set of half windings being connected up to form one mesh, and the other set of half windings connected up to form another mesh 180° out of phase with the first. In order to get this 180° phase displacement it is necessary to know whether pressure *a* to *b* is in phase with pressure *c* to *d*, or vice versa, and the same for the other phases. In any case before completing either mesh it will be necessary to test for reversed phases, and the whole may be done at one test by connecting *b-c*, *d-e*, *f-g*, *h-k*, and *l-m*, and switching in the transformer on the primary side. A voltmeter connected between *a* and *d*, *c* and *h*, or *k* and *n* should give a reading equal to twice the pressure of any one limb of either mesh—that is, to 1·224 times the continuous-current volts, whilst a reading taken between *a* and *n* should give zero. When this is satisfactory, one mesh may be completed—say 1–3–5. The vector triangle for this mesh is shown in full lines in Fig. 6. The desired vector triangle for the second mesh is as shown in dotted lines in Fig. 6, and in order to attain this it is evident that the second mesh must be made as shown by the numbers under the secondary windings. Now the first mesh may be connected up to the slip-rings 1, 3, 5, and the second mesh so connected that the ends which come opposite to 1, 3, 5 in Fig. 6 are connected to tappings diametrically opposite to 1, 3, 5 on the armature. The only possibility of error which remains is that when the slip-ring connections from the first mesh were made they were connected in the wrong direction—that is, instead of 1, 3, 5 following clockwise round the armature they should follow counter-clockwise. To check this, connect only one of the two meshes to the slip-rings through lamps, and proceed as in the phasing of a three-phase converter. It must be remembered, however, that if it is found necessary to make a crossing in these three leads the connections from the second mesh must be rearranged again to bring 4 opposite to 1, 6 opposite to 3, and 2 opposite to 5. As so much depends on knowing the leads which come vectorially opposite to 1, 3, and 5 respectively, they may be further tested after the meshes are complete, and before connecting to the slip-rings, by connecting one phase of one mesh to one phase of the other, and taking voltage readings between the remaining four leads. If two "opposite" leads are connected, the voltage read between the other two pairs will be 1·224 times the continuous-current voltage.

If no tests are made to pair out these leads in this manner it will be necessary to connect all six to the slip-rings through lamps. If correct, all the lamps will pulsate together. The lamps may, however, pulsate in pairs—each pair being formed by one lamp of each delta—which signifies that both meshes are reversed. In this case two of the leads on which lamps pulsate together should be marked, and the two remaining ones crossed in each mesh. It is also possible for four lamps—three from one delta and one from the other—to pulsate together, and the other two to follow in turn, denoting that the latter mesh is reversed. The leads connected to the last two lamps should be crossed to remedy this. There is still a further possibility that the direction of rotation of the phases in each mesh may be correct, but that one has a double crossing, compared with the connections actually desired. In this case the lamps in each delta will pulsate together, but the times of attaining brightness will not be the same for the two deltas, one set following two-thirds of a period behind the other. As there are two possible double crossings, the final connections will have to be determined by trying each of these crossings in turn.

To attain the above results, any chance of the two meshes producing voltages in phase with one another instead of 180° out of phase has been disregarded. If by any chance this were to occur, with all other connections normal, the results obtained would be very similar to the last set mentioned in the previous paragraph, the only difference being that one set of lamps lags half a period behind the other, instead of two-thirds of a period. If the other possible errors are combined with this error in mesh, another similar number of different results to the above would be obtained. It is not proposed to go into these in detail, but simply to reiterate that it is certainly advisable to make the preliminary tests mentioned, or tests calculated to eliminate similar errors.

The transformer secondaries and the slip-rings for the diametrical connections are shown in Fig. 7. The usual error of wrong rotation is possible, and there is also a possibility of a reversed phase. To test for the latter, first connect the secondaries across *b* and *c*, and *d* and *e*, and connect a voltmeter between *a* and *f*. If this reads zero, the connections made as numbered will do away with all possibility of a reversed phase. This test, and any other test which depends on connecting in star one end of the three secondary windings, must not be carried out with transformers which have had the middle points of their secondaries connected together to form a neutral for a three-wire continuous-current network until these middle points have been entirely disconnected from one another. The two points to watch in this class of rotary converters are (1) that corresponding ends of the three transformer secondaries go on to tappings 120° apart, and (2) that the two ends of each secondary are connected to tappings 180° apart.

Another test for a reversed phase is as follows: Connect three corresponding ends of the transformer secondaries to their slip-rings and leave the three remaining ends disconnected. Close the primary side of the transformer. The effect of this on the secondary windings is to connect the three in star through the armature, and the three remaining ends of the secondaries should give readings equal to 1·73 times the voltage of each limb. If a phase is reversed the effect will be the same as reversing one phase of an ordinary star winding, and the vectors will only be 60° apart instead of 120°. The reversed phase can be located from the readings.

To test for correct rotation, leave the ends already connected to the slip-rings, connect the remainder to their respective slip-rings through lamps capable of withstanding 1·4 times the continuous-current voltage, close the transformer primary, and run the machine up to synchronous speed. The lamps will pulsate as in the case of the simple three-phase machine. If the vector rotation is wrong, it is necessary to cross corresponding ends of two transformer secondaries—that is, referring to Fig. 7, cross *a* and *c*, and *b* and *d*. If the possibility of a reversed phase has not been obviated, there are two possible pulsations of the various lamps, besides those denoting correct connections and reversed rotation. In the first of these—due simply to a reversed phase—two lamps will pulsate together, with the third lamp half a cycle behind. The last lamp is connected to the reversed phase. In the second possibility—reversed phase together with wrong rotation—the lamps follow one another in brightness, but accomplish this in only half the total period, the whole three being dim for the rest of the period. The rotation is put right in the usual way, and a study of the vector diagrams will show that the reversed phase is the one connected to the lamp which comes second in the order of attaining brightness. If the two ends of each transformer secondary are not connected to diametrically opposite points on the armature winding, there are other possibilities of erratic pulsation of the lamps, but it is not proposed to examine these more closely.

Where boosters are inserted between the transformer secondaries and the armature windings it is necessary to test to ascertain that the boosting phases are connected to the correct slip-rings, so that the booster voltage adds on to the correct phases of the rotary converters. This may be done by running up the converter to about synchronous speed and taking readings of the unboosted voltage, the amount of boost, and the boosted voltage, on all three phases. If correct, the sum or difference (depending on the direction of boost) of the first two readings on all phases will equal the third reading. It is possible for one phase to be getting negative boost at the same time as the other two phases are getting positive boost, or for two phases to

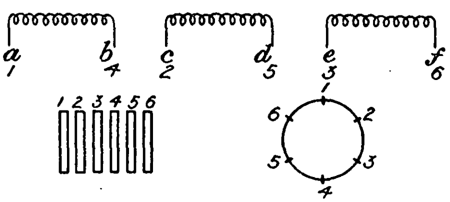

FIG. 7.

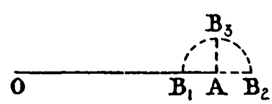

FIG. 8.

be getting each other's boost—that is, B phase getting C's boost and vice versa—or for all three phases to get the wrong boost. In the two latter cases the third reading will equal the vectorial sum of the other two instead of the arithmetical sum.

Rotary converters fitted with boosters may have them connected either between the slip-rings and the armature winding, or between the transformer secondary and the slip-rings. In the latter case it must be remembered that if any crossings are required to give the machine correct phase rotation they should be made on the transformer side of the booster. If made at the slip-rings, the boost on two phases will be changed over.

Self-starting Rotary Converters.—In three-phase rotary converters the direction in which the machine starts up when switched in determines the accuracy or otherwise of the connections, and the same applies to diametrical rotary converters whose transformers have previously been tested for reversed phase. With double-delta converters, if the preliminary tests outlined in the previous section are made, the direction of starting up will also determine the accuracy of the connections. It is sometimes stated that if the rotary converter is started up in the right direction from each delta in turn the connections are all right, but in the author's opinion this is not infallible. For example, it is quite conceivable that each delta would have the correct vector rotation, but that one of them might have a double crossing as compared with the other. Further, if the vectors of the two meshes exactly coincide, each will have the same vector rotation, but it is obvious that the connections will not answer.

Induction Regulators.

Before putting any regulator into commission it is advisable to take a test of the voltage range on all the phases. If the regulator is for high-tension work, this test may be made from a low-tension supply. This test is similar to that outlined for boosters used with rotary converters, and is made to determine if the same errors are present.

Fig. 8 shows the pressure vectors of one phase of a regulator of this class, O A being the normal supply pressure, and $A B_1 = A B_2 = A B_3$ the actual booster voltage. The variation of voltage at the boosted terminals is attained by altering the phase angle of the boosting voltage from the position $A B_1$, for maximum negative boost, to the position $A B_2$ for maximum positive boost. It is evident that so far as numerical values of voltage are concerned, the same results will be obtained by moving from B_1 to B_2 in a clockwise direction as by moving from B_1 to B_2 in a counter-clockwise direction. It would, therefore, be possible for two regulators designed to give the same voltage range, etc., to have heavy short-circuit currents flowing between them in the "no boost" position. This has to be avoided, and to test for it the two regulators may be fed from a common source of supply, and voltage readings taken between the corresponding boosted terminals of the two for several positions of the rotors.

Direct Boost Regulators.

The term "direct boost" regulators is intended to apply to that class of regulators whose vectors of boosting voltage do not differ in phase from their respective unboosted voltage vectors. These regulators usually have a booster winding with a number of tappings brought out to multiple contacts on a switch. Two moving fingers, connected in series with the line to be boosted, travel along this multiple-contact switch, and thereby allow of both the numerical value and the direction of the boosting voltage being varied. There is nothing required in the phasing-out of this particular class of regulator that has not been mentioned under "induction regulators."

In some cases, however, the two finger-contacts are not themselves connected directly in series with the line to be boosted, but are simply connected across the primary of still another transformer, the secondary of which is in series with the line. This makes it possible to have the regulating switch working at a lower voltage than the line, but this advantage is counterbalanced by the additional link required. This type of regulator offers more difficulties than are usually met with, and it is thought that a short account of the method of phasing-out will prove of interest.

Fig. 9 shows diagrammatically the connections of one boosting arrangement connected up on these lines. The supply is through a mesh-star step-up transformer, and the regulating switch itself is fed at 3,000 volts. The tapping transformer is a mesh-connected auto-transformer. It is worthy of note in passing that if in a case of this sort the step-up transformer were connected the same on both the primary and secondary sides—say, mesh-mesh—it would be necessary to have this auto-transformer star-connected, but that the mesh connection would still be required for a star-mesh transformer.

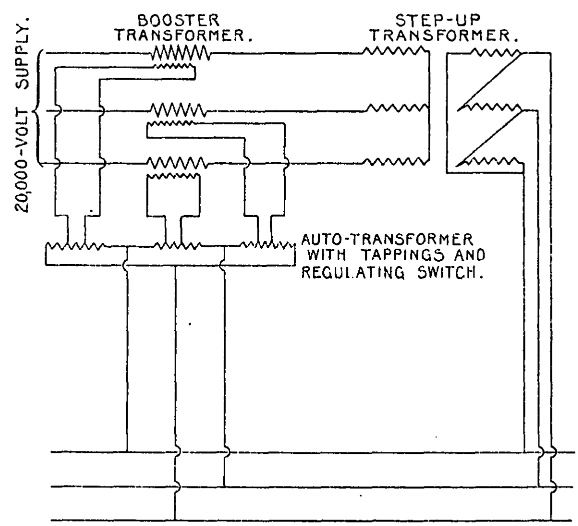

FIG. 9.

The chief point to watch in the connecting up of a regulator of this class is that the six connections between the auto-transformer and the booster transformer are correctly paired. A step-voltage test is now taken in the same way as with other regulators. The low-tension supply is connected to the 3,000-volt busbars, or where these have to be left in commission the cables connecting the auto-transformer and the main step-up transformer to the busbars are connected together and the low-tension supply applied directly to them. In the particular case under discussion, however, if a 440-volt supply were used, the pressure on the secondary of the step-up transformer would be in the neighbourhood of 2,000 volts, or far too high for conveniently taking voltage readings. To get over this, the 440-volt supply is applied to the step-up transformer secondary, the 3,000-volt cables being connected across as before. This gives a convenient pressure at the booster terminals for a test of this nature. The regulator is put in one of the extreme positions, and readings are taken of the boosting volts and of the unboosted and boosted volts. The faults possible are the same as those previously outlined, and may be recognized in the same way. If the connections between the auto-transformer and the booster are not correctly paired, the results obtained would be more complex, but as it is always a simple matter to test out for these pairs, it is not considered necessary to look any further into these possibilities.

In conclusion, the author would like to express his indebtedness to Mr. G. L. Porter for several suggestions which have proved very useful in preparing this paper.